Weekly Journal Club for Medium Energy Physics
Institute of Physics, Academia Sinica

Time-Of-Flight Resistive Plate Chamber

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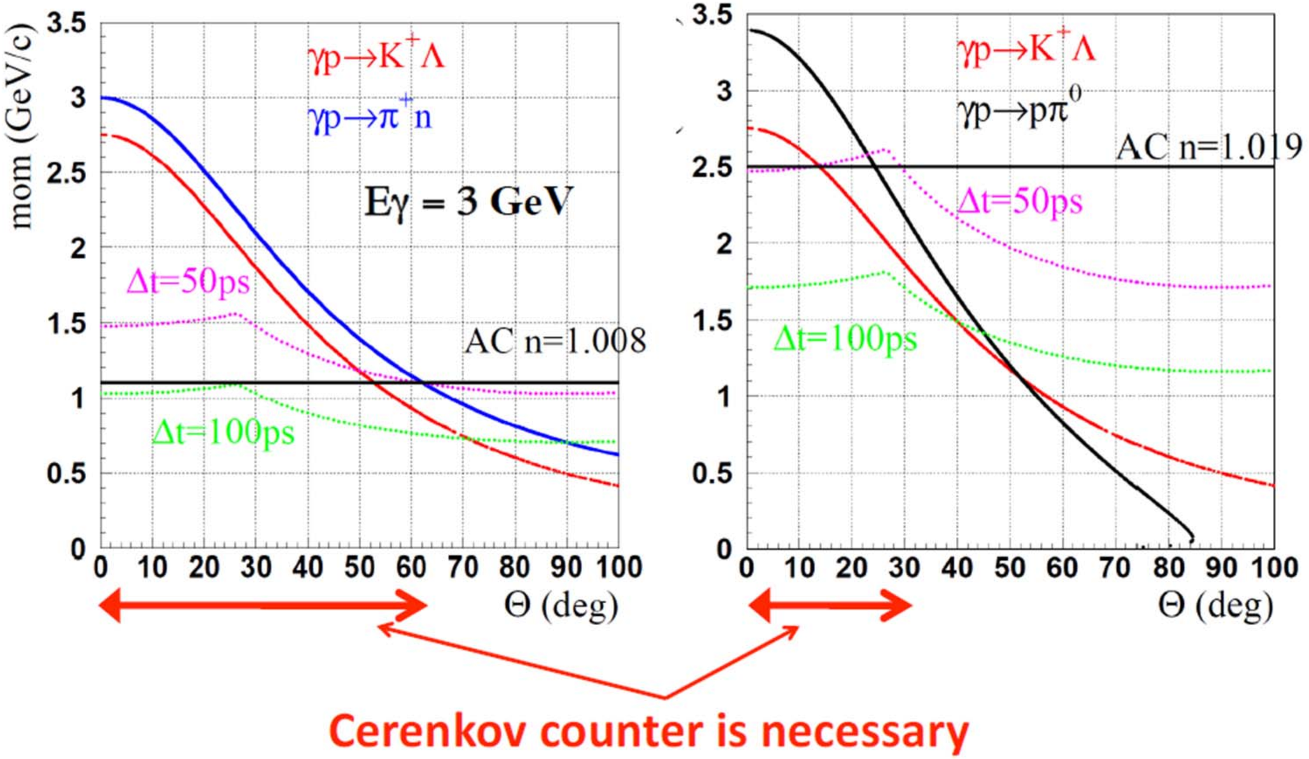
Outlines

- Motivation
  - Particle Identification at SPring-8/LEPS2
- Introduction
  - History & Advantage
  - Detector Physics
  - Construction
- Beam Test at SPring-8(Japan)
- Beam-Test Results
- Future Studies

Motivation (Particle Identification)

K/π/p separation by TOF counter



Before Resistive Plate Chamber (1)

- Spatial resolution
  - DC operating gaseous detectors of ionizing particles, such as wire/drift chambers and streamer tubes have successfully replaced the order technique of the scintillator coupled to photomultipliers in experiments requiring a high spatial resolution.

Before Resistive Plate Chamber (2)

- Time resolution
  - The fluctuation of time needed by electrons liberated in the gas by an ionizing particle, to drift up to the multiplication region, very close to the wire, where avalanches and eventually streamer are produced.
  - Scintillator, the most commonly utilized technique for high time resolution, before 1990.
  - A higher time resolution is clearly achievable if an uniform and intense electric field is used instead of that produced by a charged wire. The sequence of transitions, “free electrons → avalanche → streamer”, can occur in a very short time and with minimal fluctuations.

Advantages of RPC

- Time resolution is down to 50 ps.
- Larger covering areas up to a few thousand square meters.
- Robustness and simplicity of construction.
- Inexpensive industrial production.

Principle of RPC (1)

- An RPC is a particle detector utilizing a constant and uniform electric field produced by two parallel electrode plates. When the gas (Freon) is ionized by a crossing charged particle, an electric discharge is initiated by the liberated electrons. This discharge is quenched by the following mechanisms:
  - The discharge is prevented from propagating through the whole gas, because of the high resistivity (~10^{10} Ωm) of electrodes. The electric field is suddenly switched off around the discharge point, out of this area (~0.1 cm^2) the sensitivity of RPC remains unaffected.
  - UV photons produced by the discharge were absorbed by the isobutane/butane to avoid secondary discharges from gas photoionization.
  - Capture of outer electrons of the discharge due to the Freon affinity, which reduces the size of the discharge and possibly its transversal dimensions.

Principle of RPC (2)

- The RPC consists of two parallel plate electrodes with high volume resistivity. A charge Q_0 that enters the resistive electrode surface “decomposes” with time t following an exponential

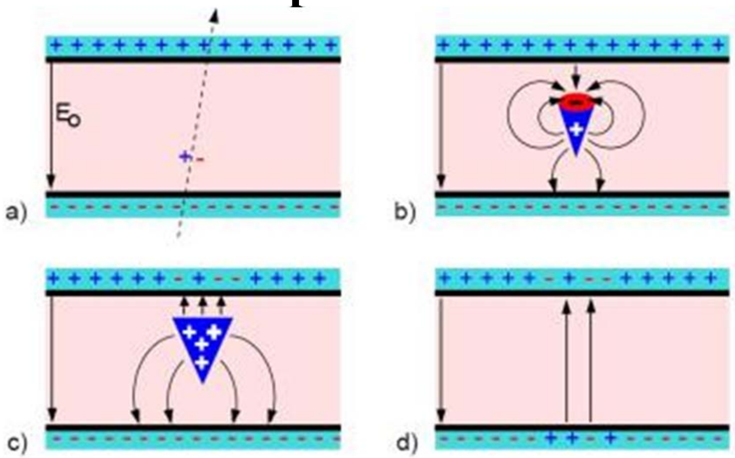
$$Q(t) = Q_0 e^{-t/\tau} \text{ with } \tau = \rho\epsilon_0\epsilon_r$$

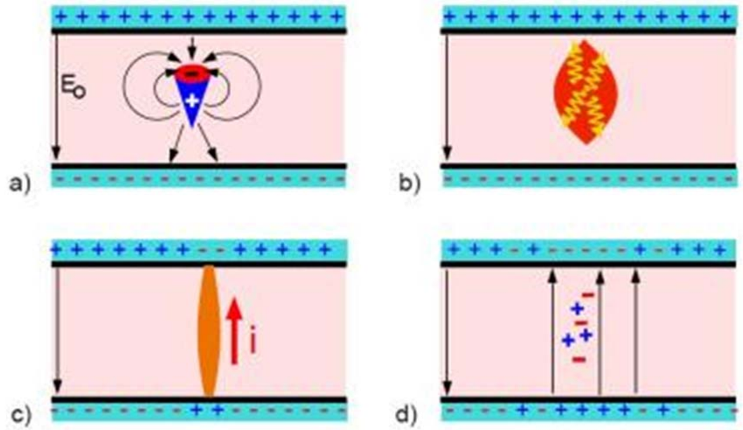
where τ is the relaxation time.

$$\tau = 10^{10}\ \frac{kg \cdot m^3}{s^3 \cdot A^2} \times 8.854 \times 10^{-12} \frac{A^2 s^4}{m^3 \cdot kg} \times 4.7 = 0.41\ s$$

- The duration time of discharge is typically ~ 10 ns. The relaxation time of resistive electrode plates is of the order of τ ~ 0.41 second. The large difference between these two characteristic times insures that during the discharge the electrode plates behave like insulators.

RPC Operation Modes





avalanche mode

- some gas atoms are ionized by the passage of a charged particle. An avalanche is started.
- The avalanche size is sufficiently large to influence the electric field in the gas gap.
- The electrons reach the anode. The ions drift much slower.
- The ions reach the cathode.

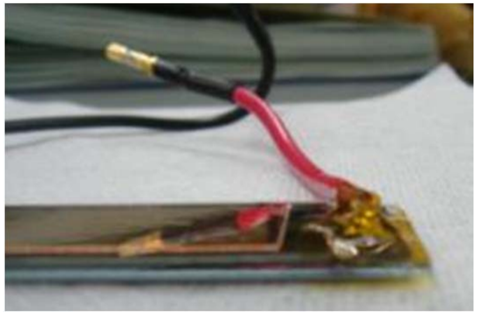
streamer mode

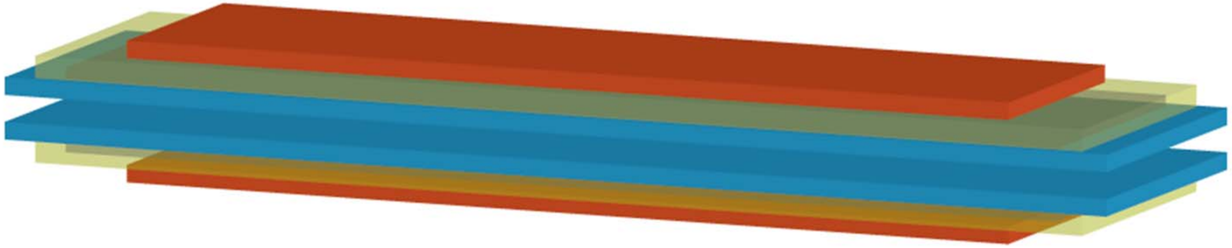
- An avalanche is developing.
- The avalanche charges lead to a high field deterioration in the gas gap. Moreover, photons start to contribute to the avalanche development and cause a rapid spread of the avalanche : A streamer evolves.
- A weak spark may be created. The local electrode area is discharged.
- The electric field is strongly decreased around the spot of the avalanche.

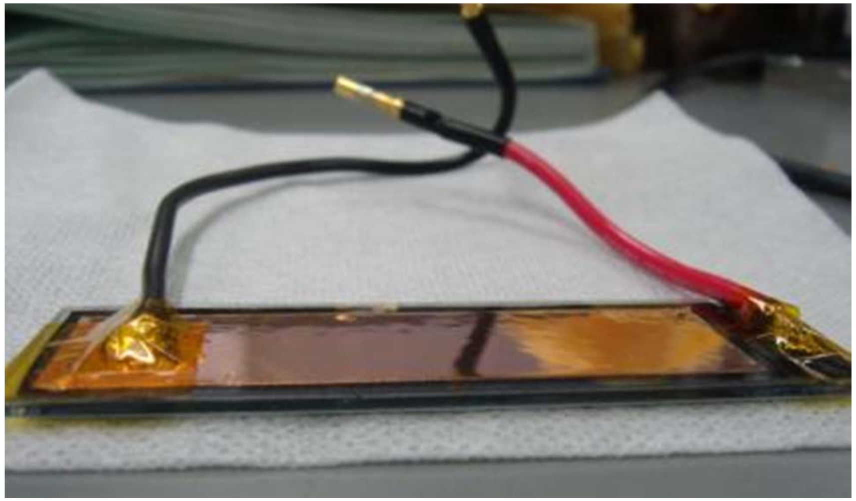
Comparison of RPC Operation Modes

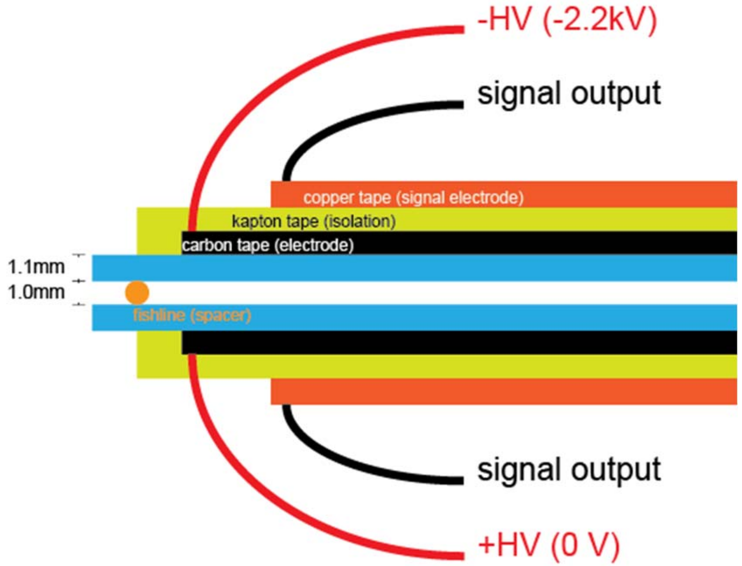
- Streamer mode
  - Providing large signals, which simplifies read-out electronics and gap uniformity requirement, but having the aging issue and low detected rate.
- Avalanche mode
  - The signal generated in avalanche mode is not large enough and the amplifier device is usually required.
  - High-rate application and the detector aging problem were facilitated by the development of highly quenching $C_2F_4H_2$-based gas mixtures with the addition of small contents of SF_6.

Single-gap RPC Configuration





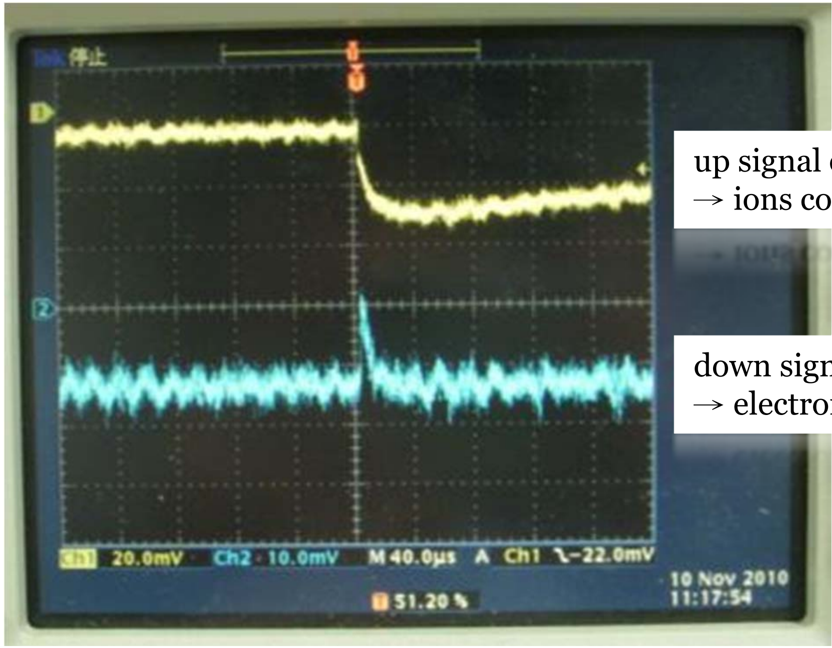




Single-gap RPC Test

2010/11/09 @ RIKEN, Japan

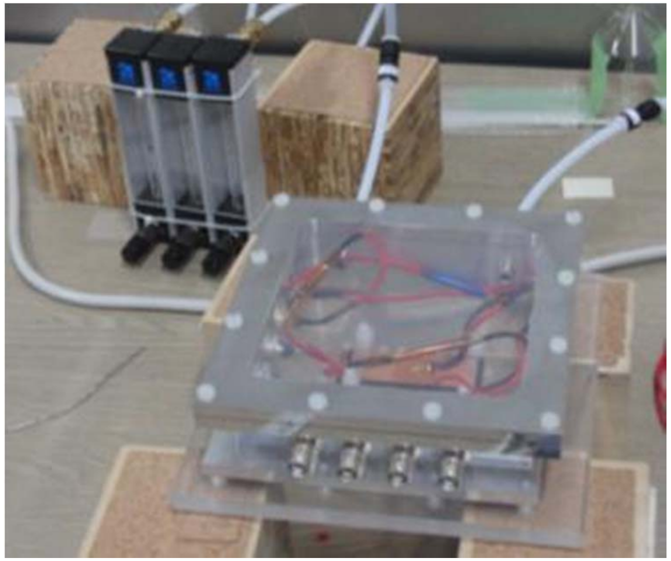
signals taken by using 10-MΩ probe



up signal electrode
→ ions collection

down signal electrode
→ electrons collection

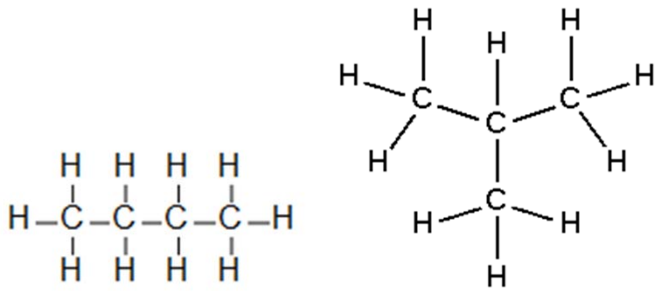
HV (up) : -2.2 KV HV (down) : 0 V



Gas Mixtures

- R134A (Freon/$C_2F_4H_2$) : 90%
  - Ionization
- Isobutane : 5%
  - UV photons absorption
- SF_6 : 5%
  - Avalanche mode

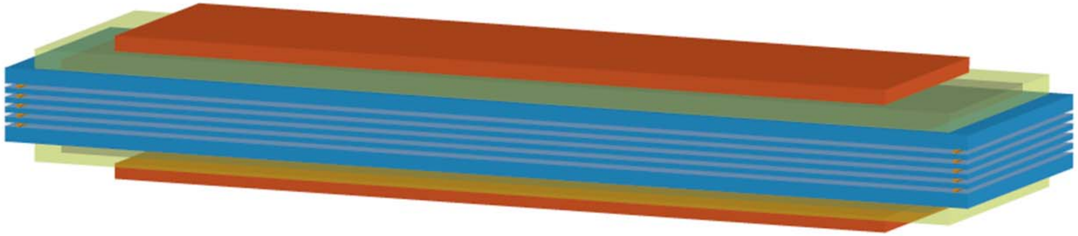
RPC Performance Factors

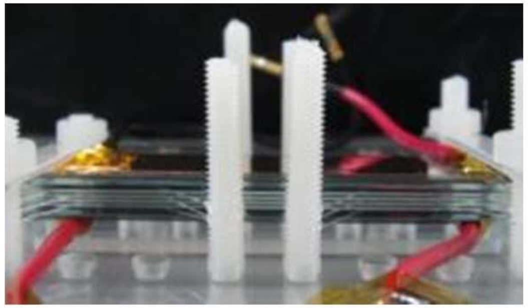


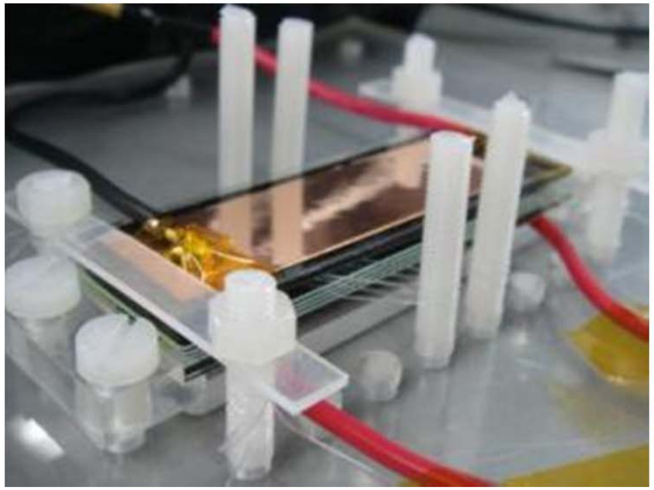
Butane Isobutane

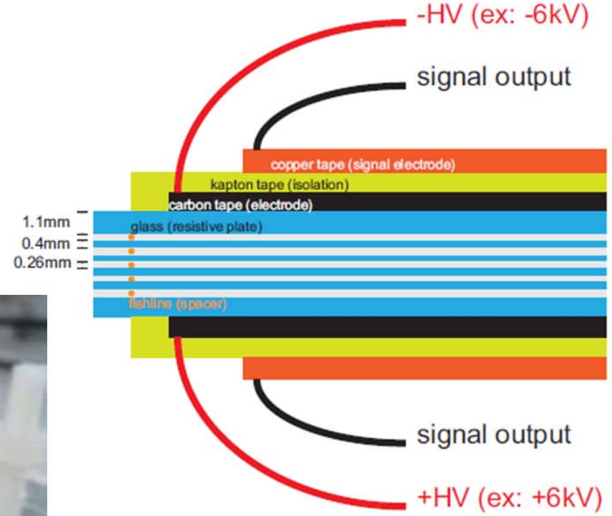
- Operation HV (10~11 KV/1mm)
- Gas component
  - Isobutane/Butane : expensive/cheaper, higher/lower efficiency
- RPC # of layers
  - more layers : better efficiency, larger pulse height, much noiser to calorimeter
- Gas gap : Creating the primary ionization clusters, Gas gain
  - narrower : better time resolution, lower efficiency
  - wider : larger signal (especially in avalanche mode), worse time resolution (larger arrival-time fluctuation), therefore the multi-gap RPC was proposed.

Multi-gap RPC Configuration (5 gaps)





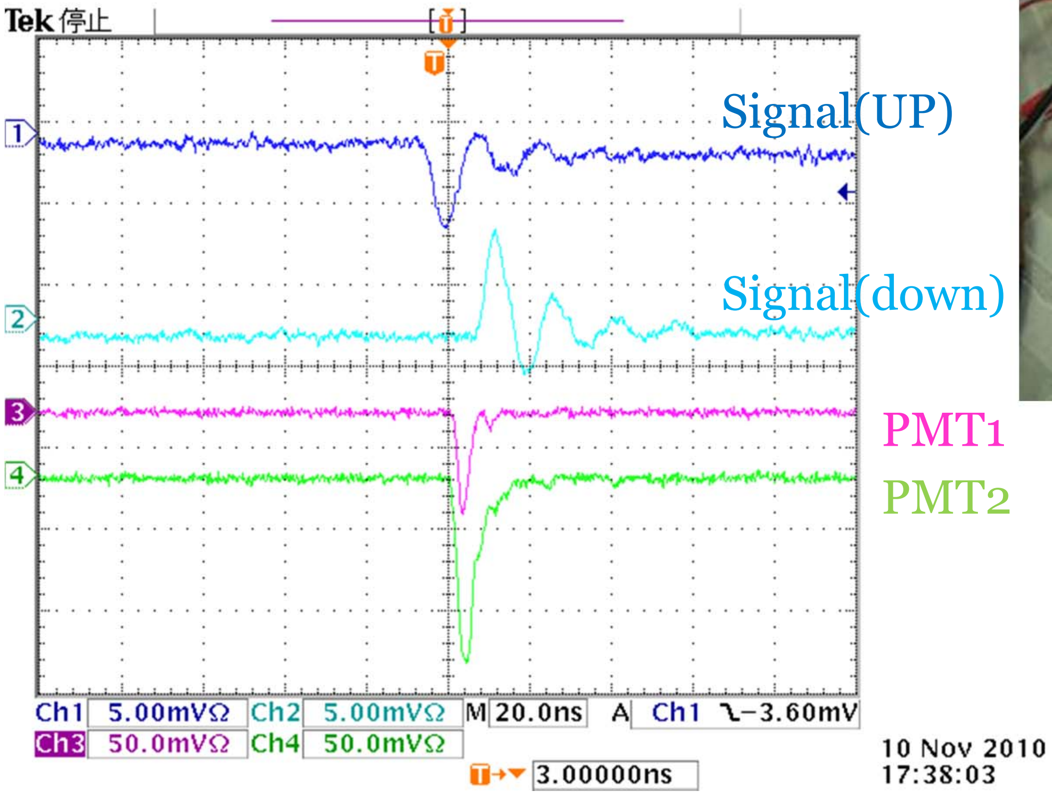


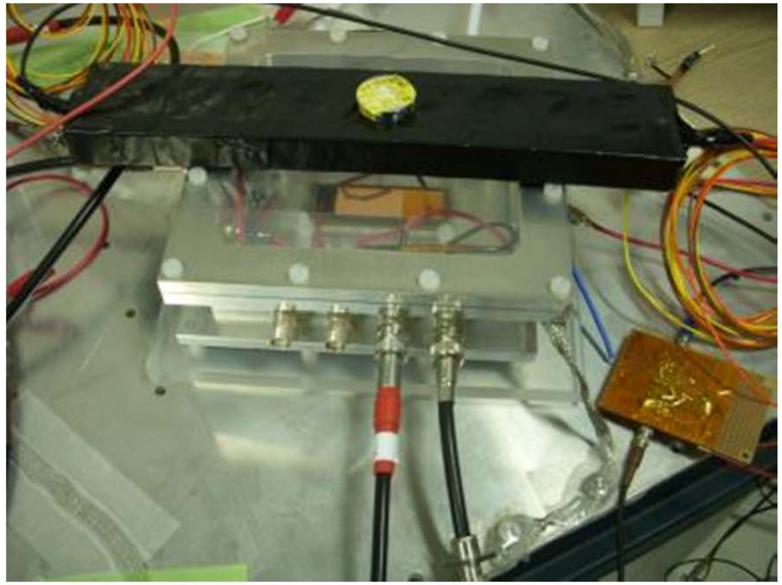


Multi-gap RPC consists of resistive plates and gas gaps stacked alternatively, and electrodes are placed on the outer surface of the most outer resistive plates.

Multi-gap RPC Test

Sr (β source)





1 Scintillator with 2 PMT outputs Coincidence

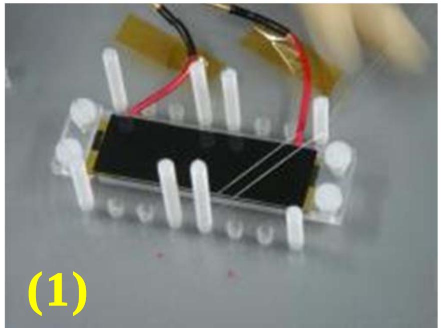
HV_{up} = -3.6KV

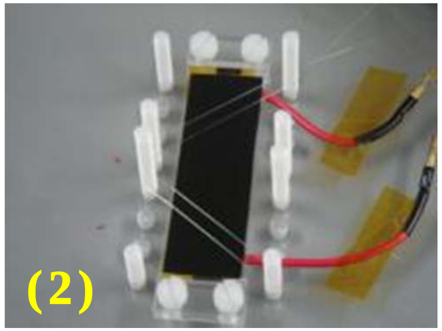
HV_{down} = 0 V

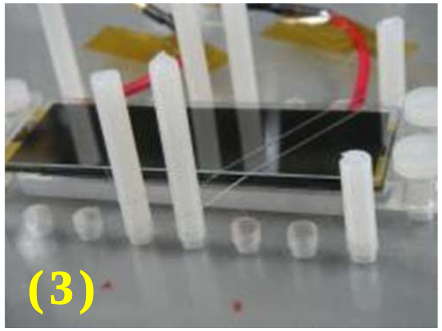
Multi-gap RPC

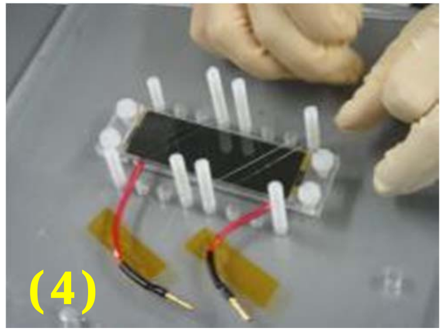
- The HV is applied by a resistive layer only to the external surfaces of the external plates; all the internal resistive plates are all **electrically floating**, the time jitter are reduced by small size of sub-gaps.
- Pickup electrodes are located outside the stack and insulated from the HV electrodes.
- The resistive plates act as “dielectrics”, that is, the resistive plates are **transparent** to the fast signal generated by the avalanches inside each gas gap. Induced signal can be caused by the movement of charge in anywhere of gas gaps between 2 pickup electrodes. Therefore, the observed induced signal is the **sum** of the individual avalanche signal.

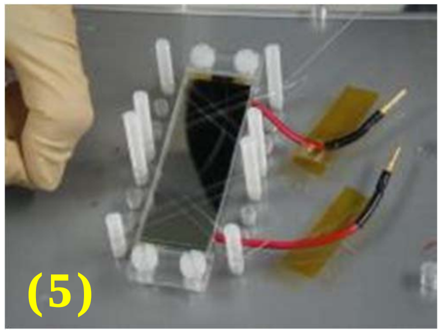
Multi-gap RPC Construction

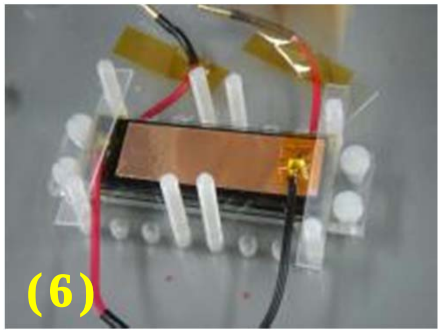


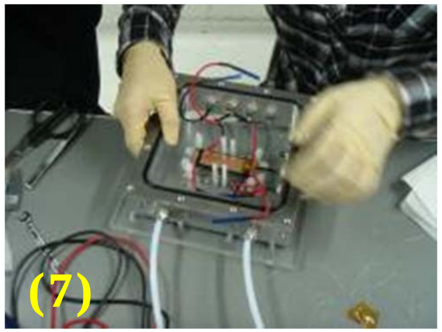


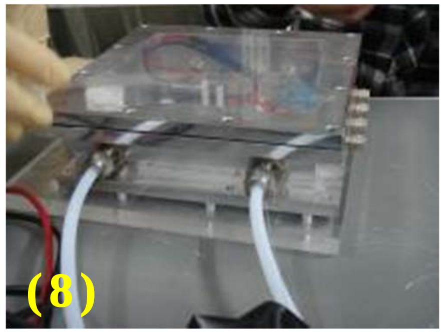




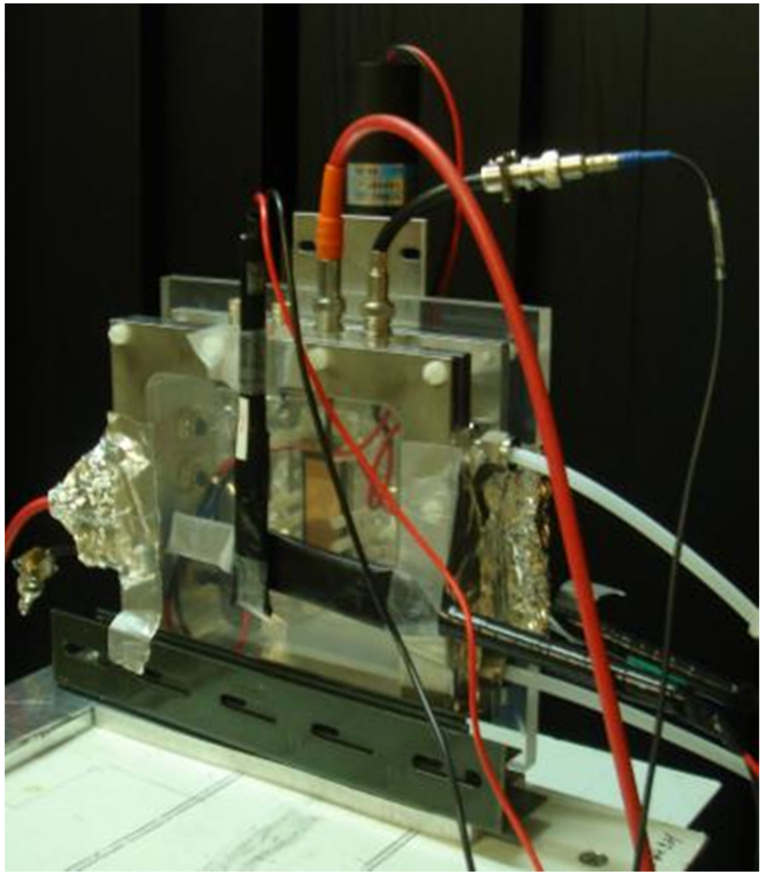


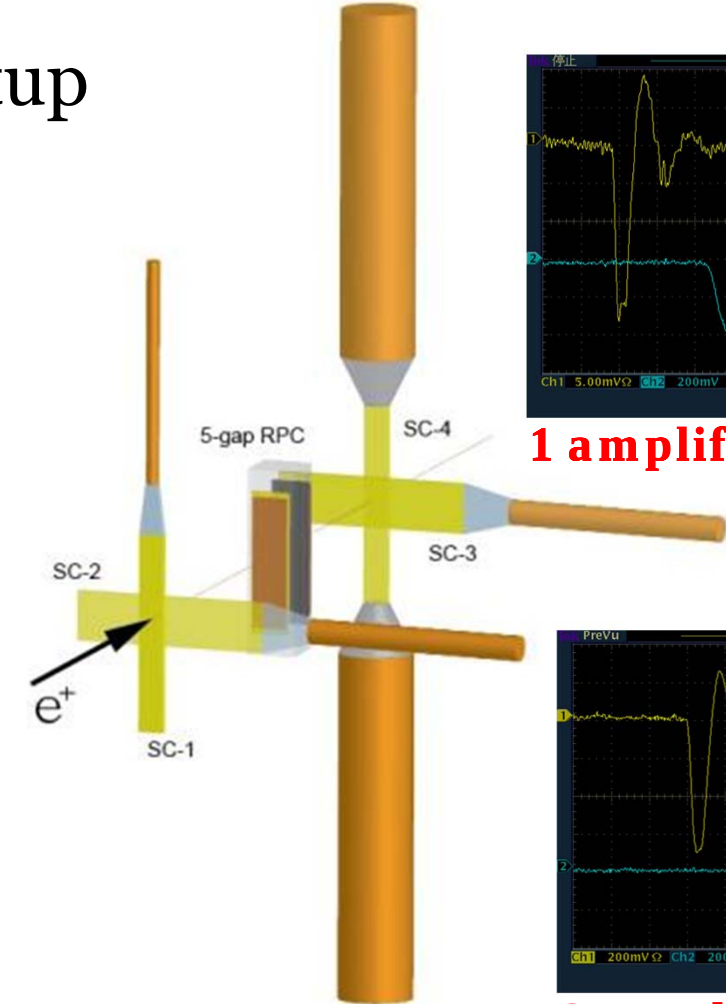


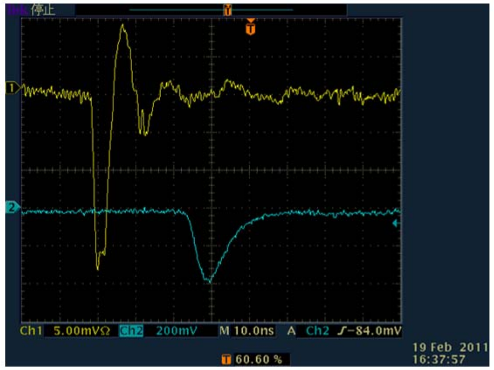




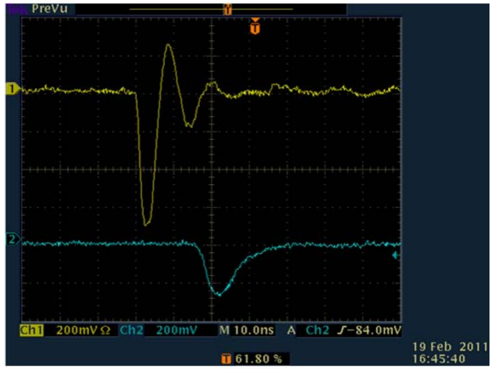
MRPC Beam Test Setup







1 amplifier



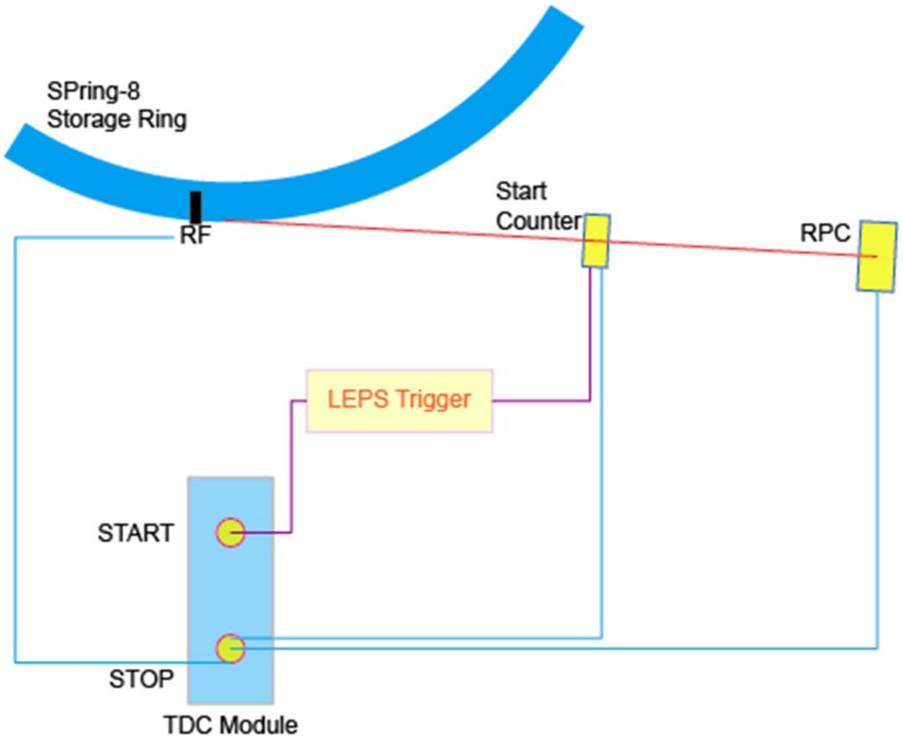
3 amplifiers

Studies of MRPC Time Resolution

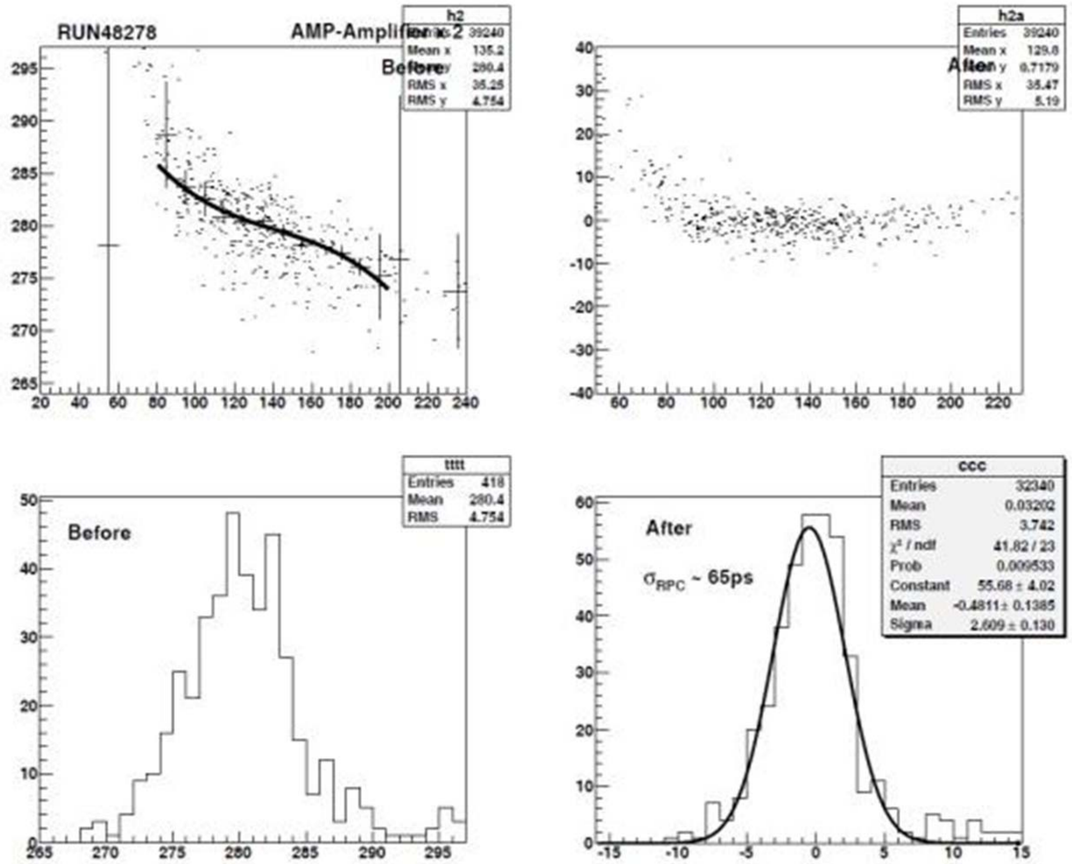
- Efficiency (# of RPC layers, HV, gas components)

$$Eff = \frac{sc1 \times sc2 \times sc3 \times sc4 \times RPC}{sc1 \times sc2 \times sc3 \times sc4}$$

- Time Resolution (spacer, pre-Amplifier, jitter effect)
  - $TDC_{RF} - TDC_{RPC}$ $\delta_{RF}{}^2 + \delta_{RPC}{}^2$
  - $TDC_{RF} - TDC_{SC}$ $\delta_{RF}{}^2 + \delta_{SC}{}^2$
  - $TDC_{RPC} - TDC_{SC}$ $\delta_{RPC}{}^2 + \delta_{SC}{}^2$

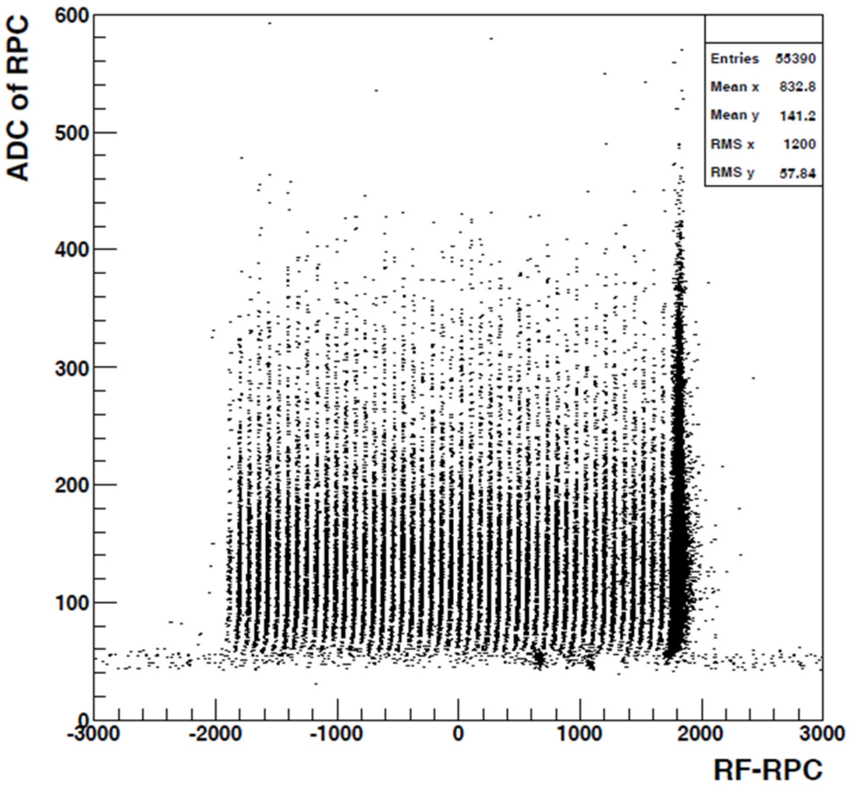


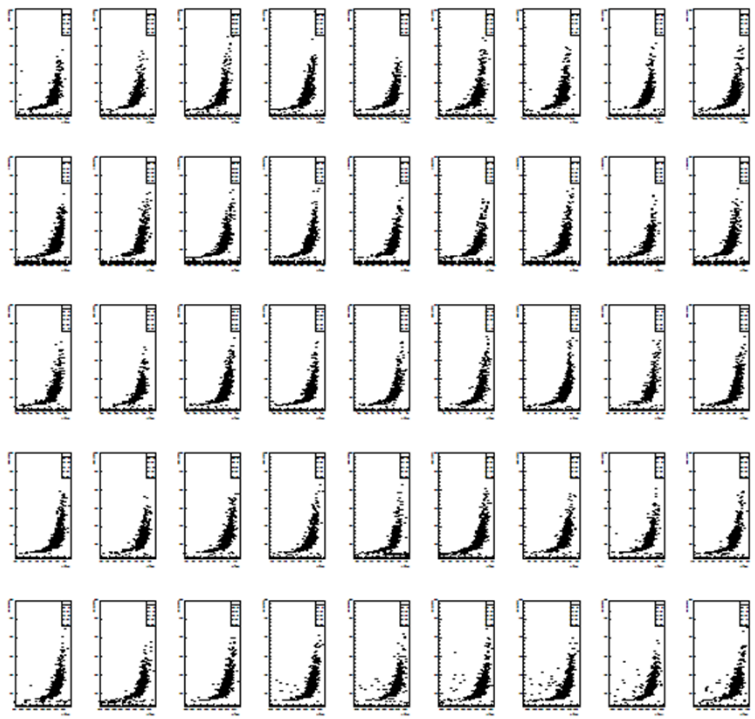
MRPC Beam Test Result (1)



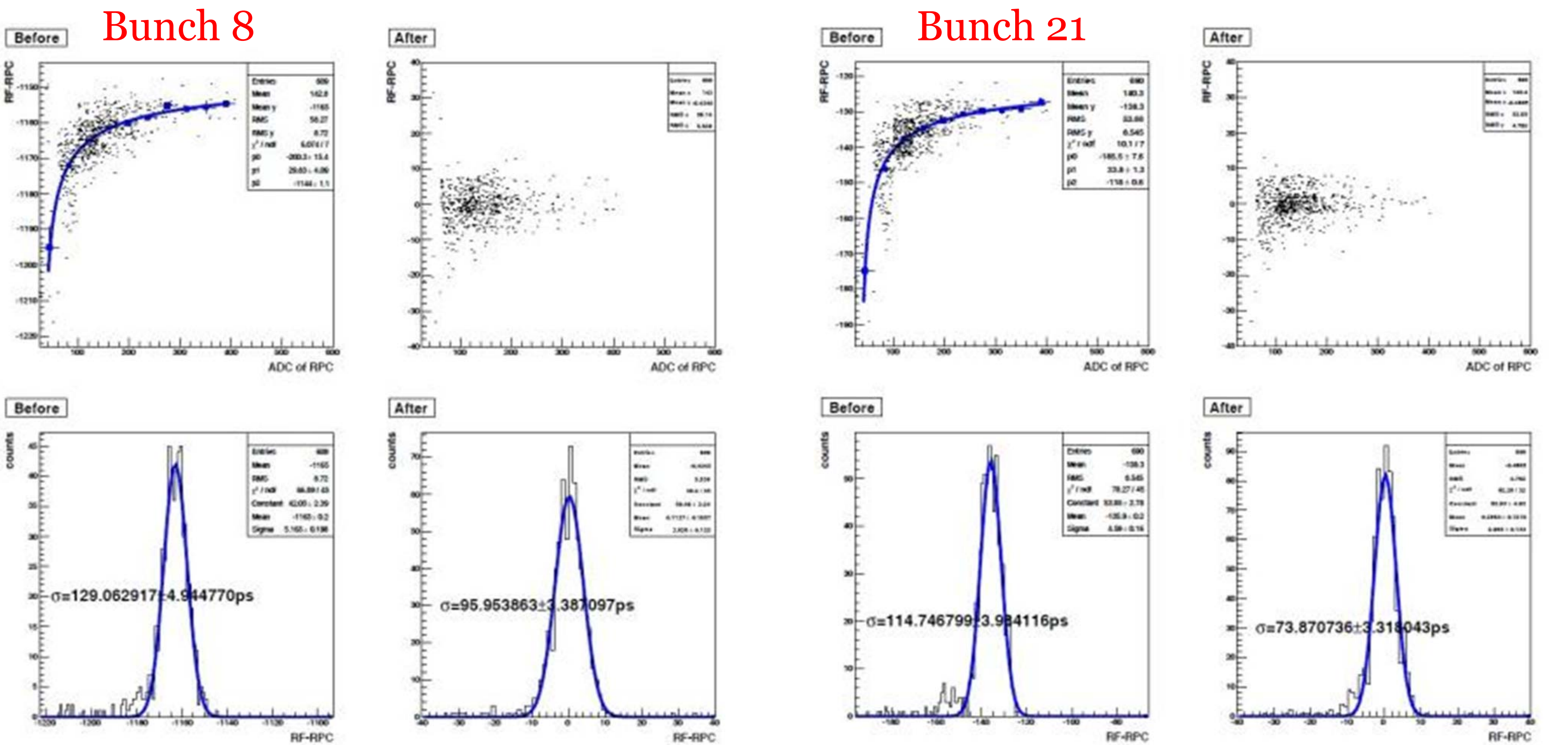
- Each TDC bin is 25 ps.
- Efficiency
  - Isobutane > 95%
  - Butane > 90 %
- First time-resolution result was studied by Ohnishi-san, after applying the slewing correction.
  - σ_t ~ 65 ps

MRPC Beam Test Result (2)

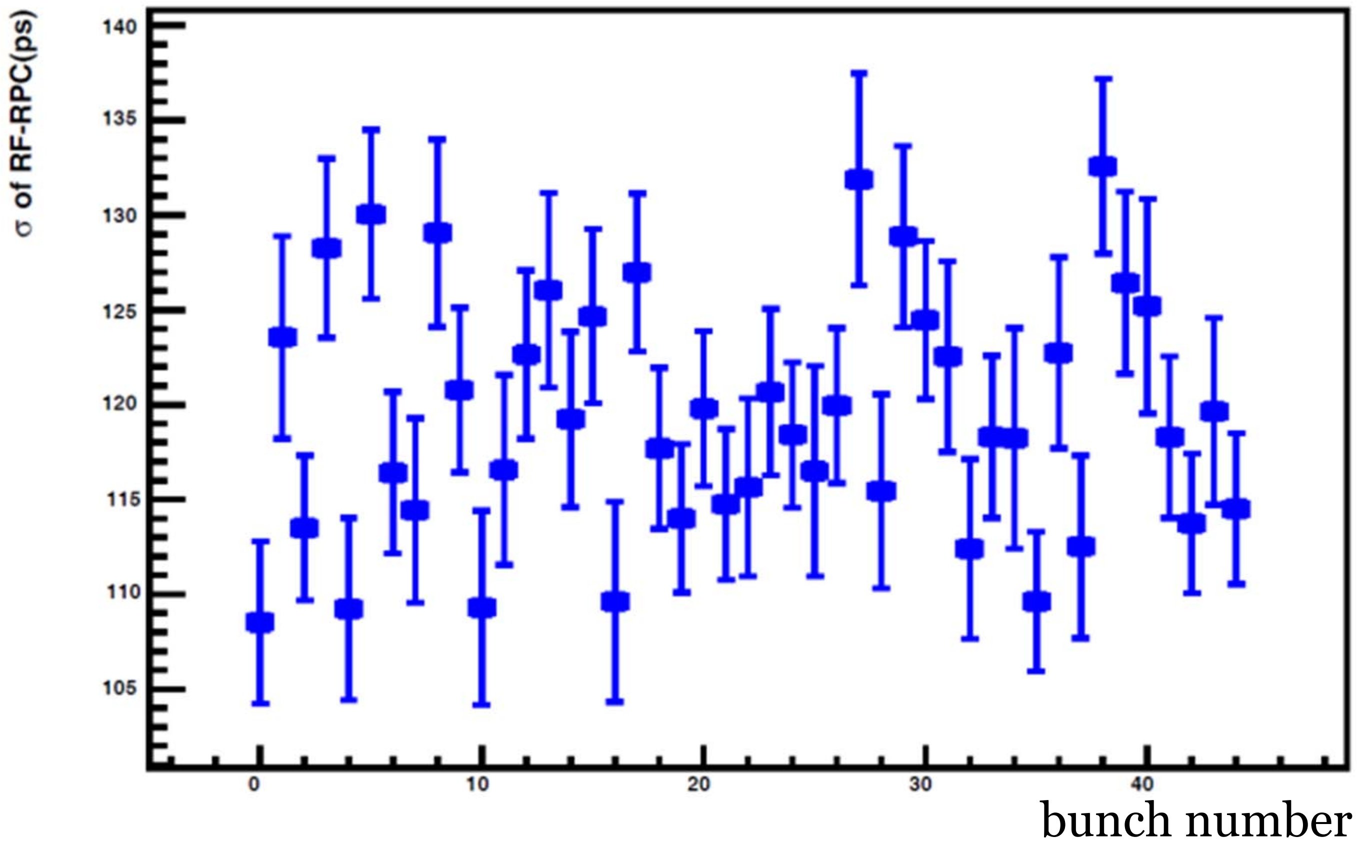




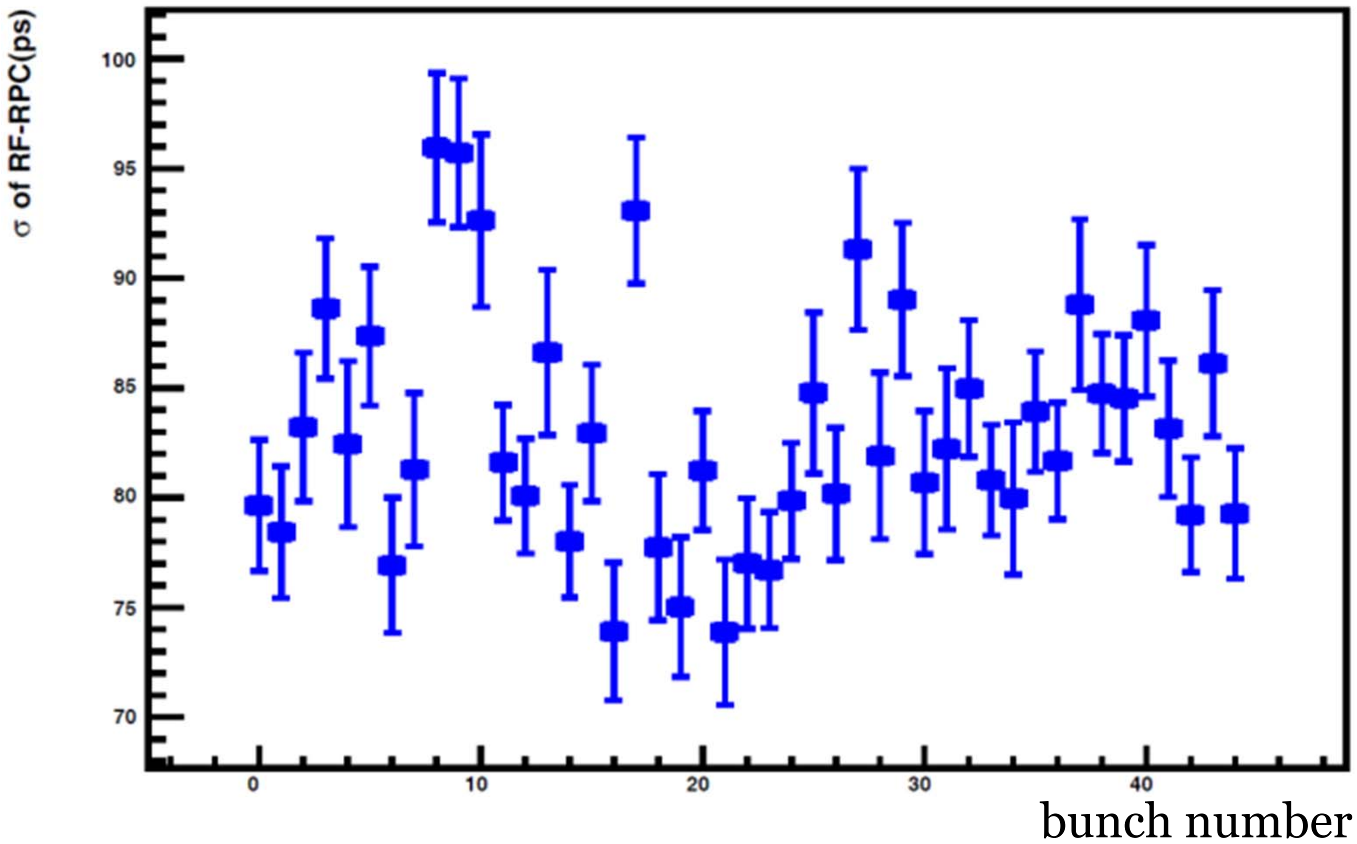
MRPC Beam Test Result (3)



MRPC Beam Test Result (Before Slewing Correction)



MRPC Beam Test Result (After Slewing Correction)

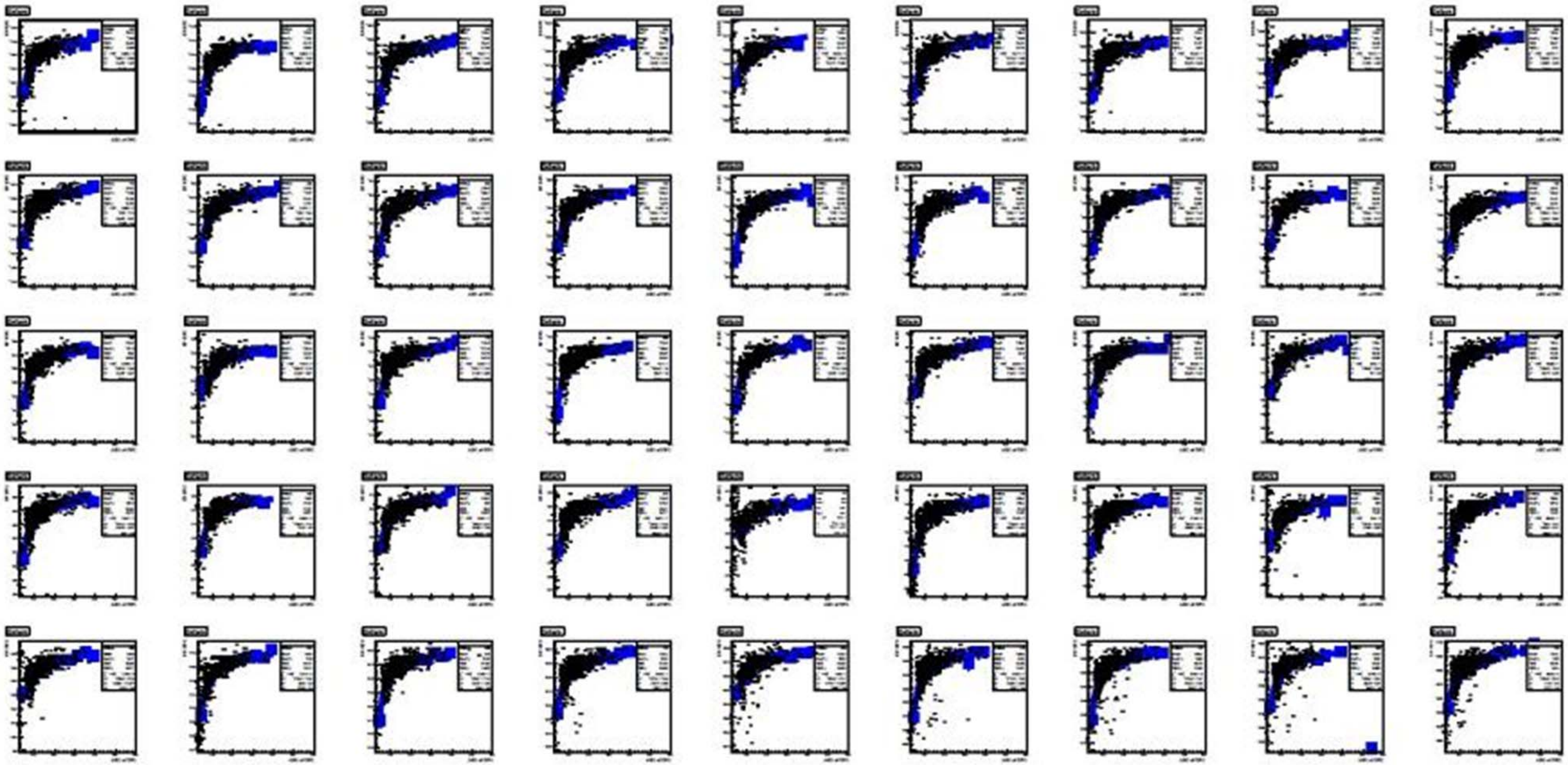


Future Studies

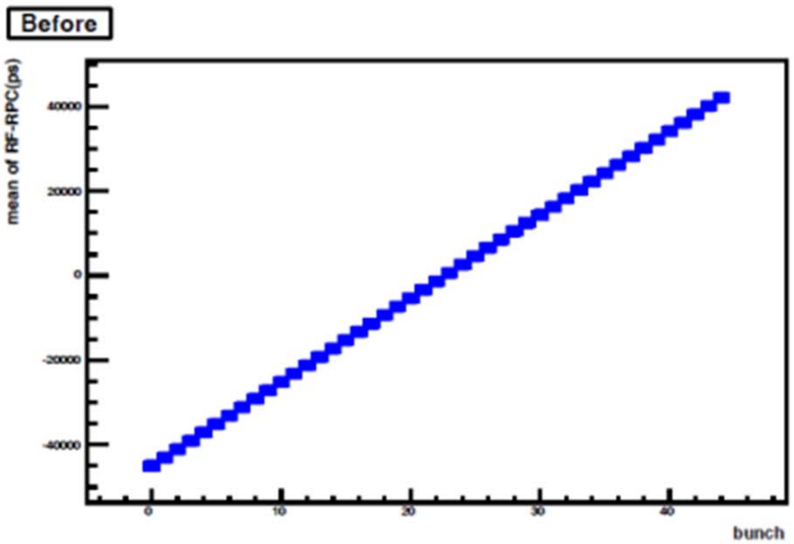
- MRPC Construction Uniformity
- Efficiency
  - single rate of RPC
  - improve the efficiency by using Butane, after considering the cost.
- Time resolution
  - time resolution of Start Counter
    - σ_{SC}=90ps is different from previous LEPS results, 180 ps.
  - RF bunch dependence (must be non-dependence)
  - build suitable pre-Amplifier (refer to RHIC PHENIX experiment)

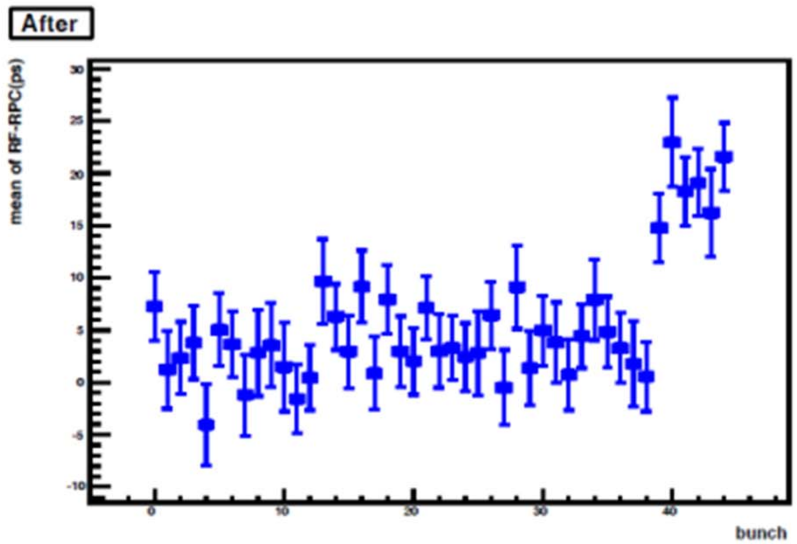
Backup Slices

MRPC Beam Test Result

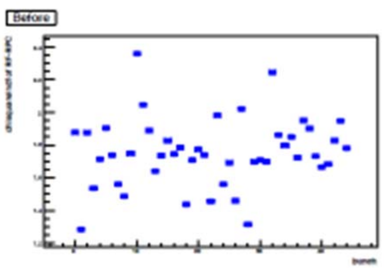


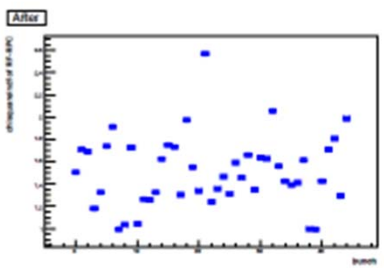
Mean Position After Slewing Correction





x^2





Dielectric

- A dielectric is an electrical insulator that can be polarized by an applied electric field. When a dielectric is placed in an electric field, electric charges do not flow through the material, as in a conductor, but only slightly shift from their average equilibrium positions causing dielectric polarization. Because of dielectric polarization, positive charges are displaced toward the field and negative charges shift in the opposite direction. This creates an internal electric field that partly compensates the external field inside the dielectric.
- If a dielectric is composed of weakly bonded molecules, those molecules not only become polarized, but also reorient so that their symmetry axis align to the field.